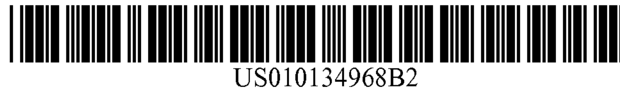

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Schubert

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(45) **Date of Patent: Nov. 20, 2018**

(54) **SOLID STATE LIGHTING DEVICES WITH IMPROVED CONTACTS AND ASSOCIATED METHODS OF MANUFACTURING**

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(Continued)

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H01L 33/62 (2010.01)
H01L 33/10 (2010.01)

(Continued)

(52) **U.S. Cl.**

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(Continued)

(58) **Field of Classification Search**

CPC . H01L 2933/0066; H01L 33/10; H01L 33/60; H01L 33/405; H01L 33/42;

(Continued)

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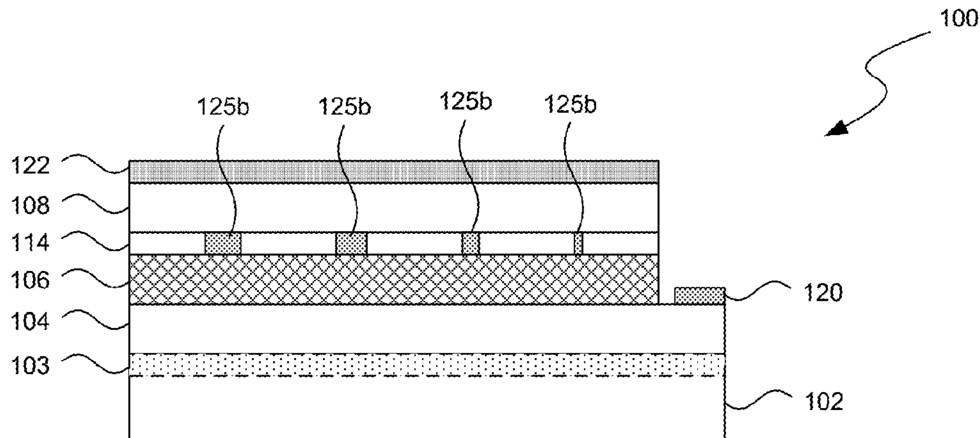
(74) *Attorney, Agent, or Firm* — Perkins Coie LLP

(57) **ABSTRACT**

Solid state lighting ("SSL") devices with improved contacts and associated methods of manufacturing are disclosed herein. In one embodiment, an SSL device includes an SSL structure having a first semiconductor material, a second semiconductor material spaced apart from the first semiconductor material, and an active region between the first and second semiconductor materials. The SSL device also includes a first contact on the first semiconductor material and a second contact on the second semiconductor material, where the first and second contacts define the current flow path through the SSL structure. The first or second contact is configured to provide a current density profile in the SSL structure based on a target current density profile.

5 Claims, 9 Drawing Sheets



Related U.S. Application Data

of application No. 12/872,092, filed on Aug. 31, 2010, now Pat. No. 8,664,684.

(51) **Int. Cl.**

H01L 33/42	(2010.01)
H01L 33/40	(2010.01)
H01L 33/44	(2010.01)
H01L 33/60	(2010.01)
H01L 33/38	(2010.01)
H01L 33/46	(2010.01)
H01L 33/36	(2010.01)
H01L 33/06	(2010.01)
H01L 33/14	(2010.01)
H01L 33/32	(2010.01)
H01L 51/52	(2006.01)

(52) **U.S. Cl.**

CPC ***H01L 33/32*** (2013.01); ***H01L 33/36*** (2013.01); ***H01L 33/38*** (2013.01); ***H01L 33/382*** (2013.01); ***H01L 33/385*** (2013.01); ***H01L 33/387*** (2013.01); ***H01L 33/40*** (2013.01); ***H01L 33/405*** (2013.01); ***H01L 33/42*** (2013.01); ***H01L 33/44*** (2013.01); ***H01L 33/46*** (2013.01); ***H01L 33/60*** (2013.01); *H01L 51/5212* (2013.01); *H01L 2251/5361* (2013.01); *H01L 2924/0002* (2013.01); *H01L 2933/0016* (2013.01); *H01L 2933/0025* (2013.01); *H01L 2933/0066* (2013.01)

(58) **Field of Classification Search**

CPC H01L 33/44; H01L 33/46; H01L 33/36; H01L 33/38; H01L 33/382; H01L 33/385; H01L 33/387; H01L 33/40; H01L 2933/0016

See application file for complete search history.

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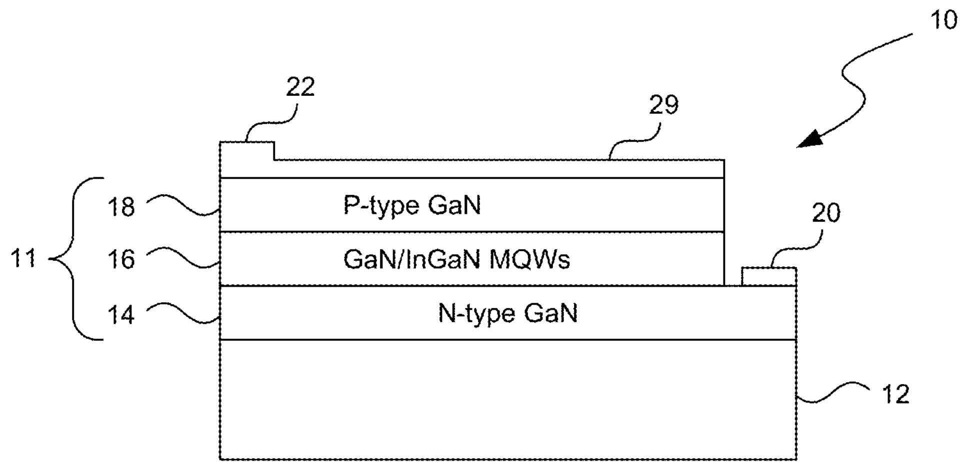

FIG. 1A
(Prior Art)

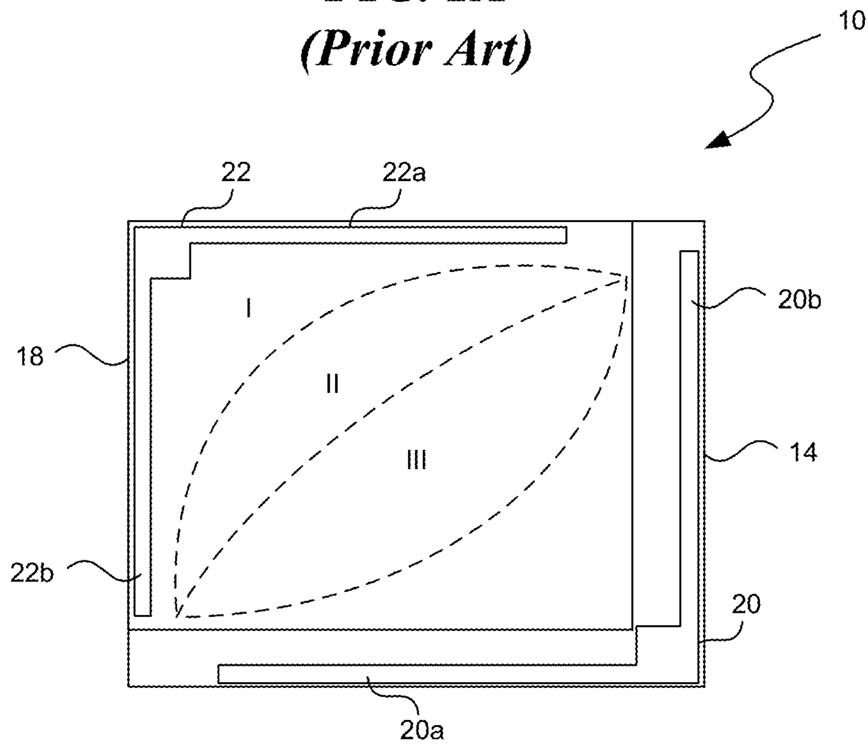

FIG. 1B
(Prior Art)

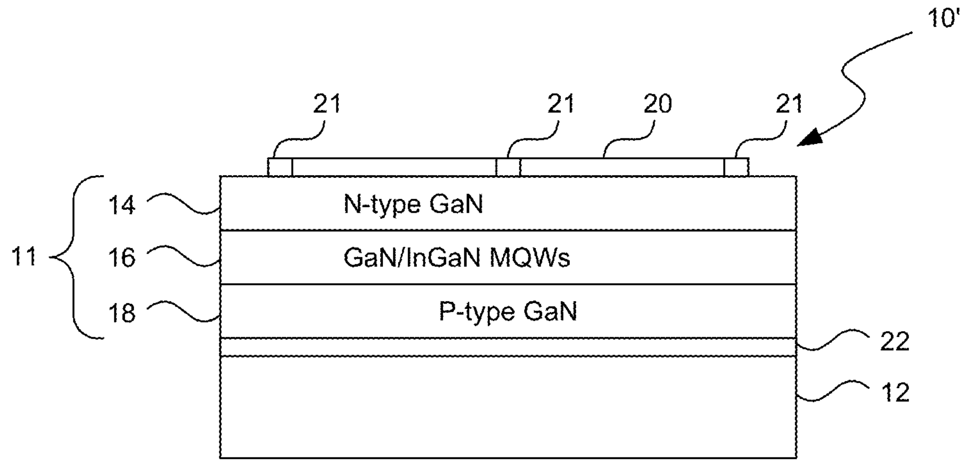

FIG. 2A
(Prior Art)

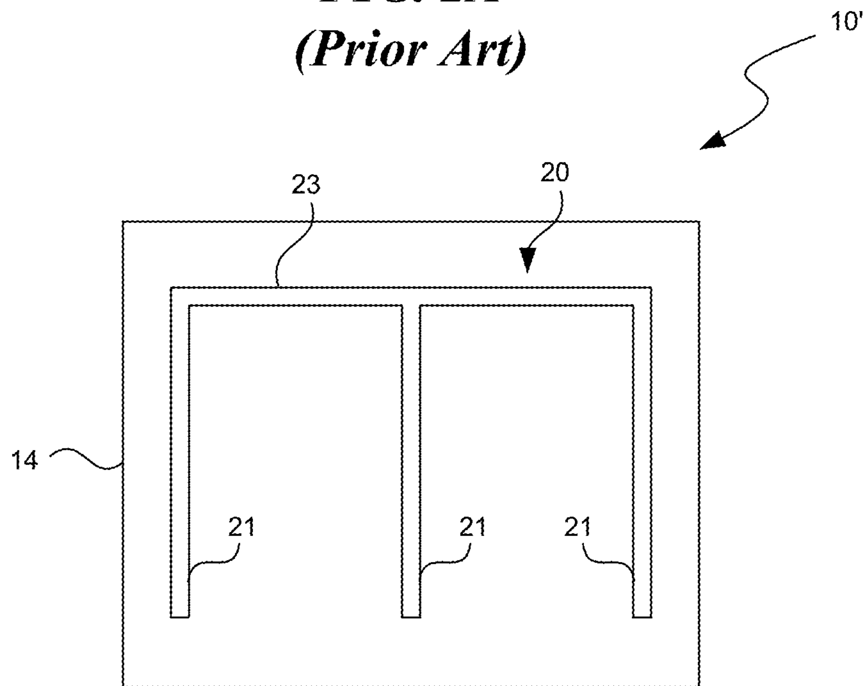

FIG. 2B
(Prior Art)

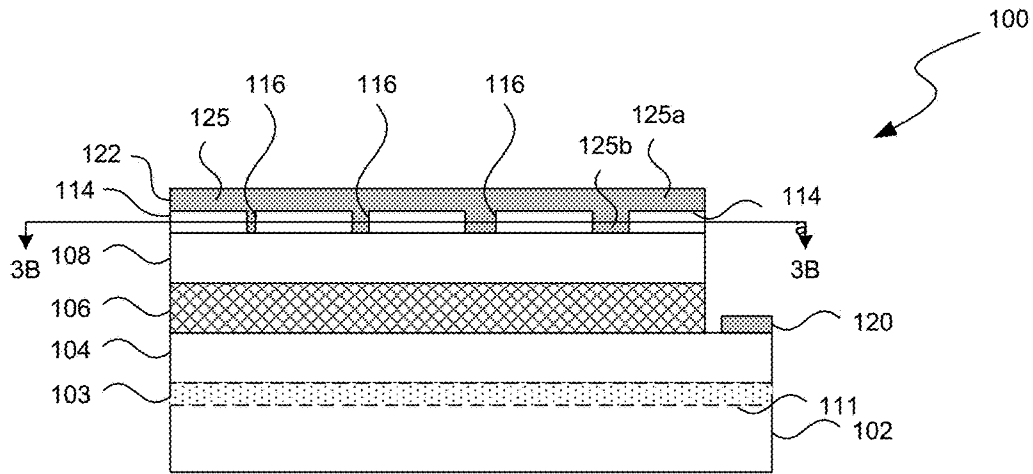

FIG. 3A

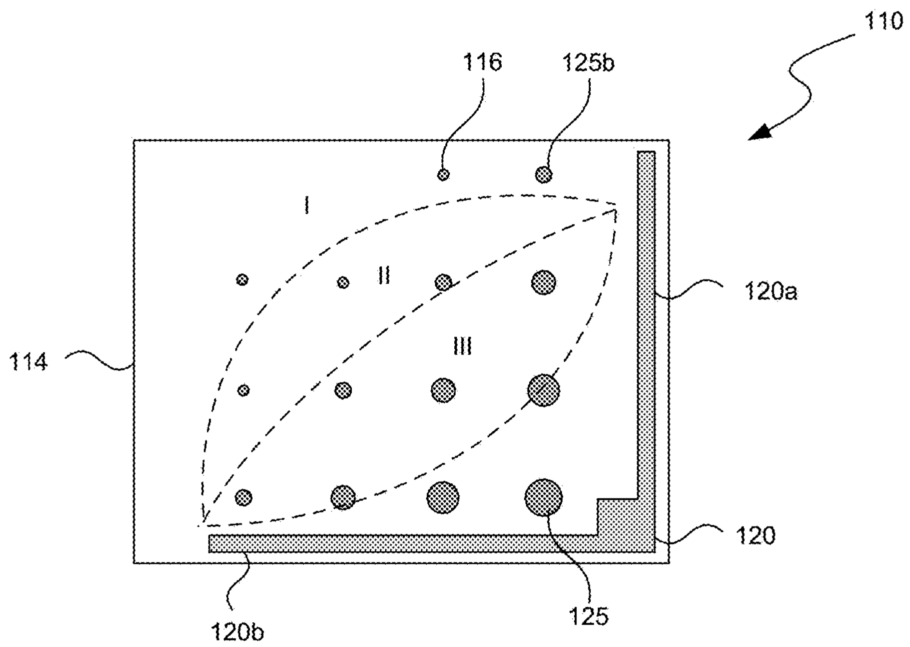

FIG. 3B

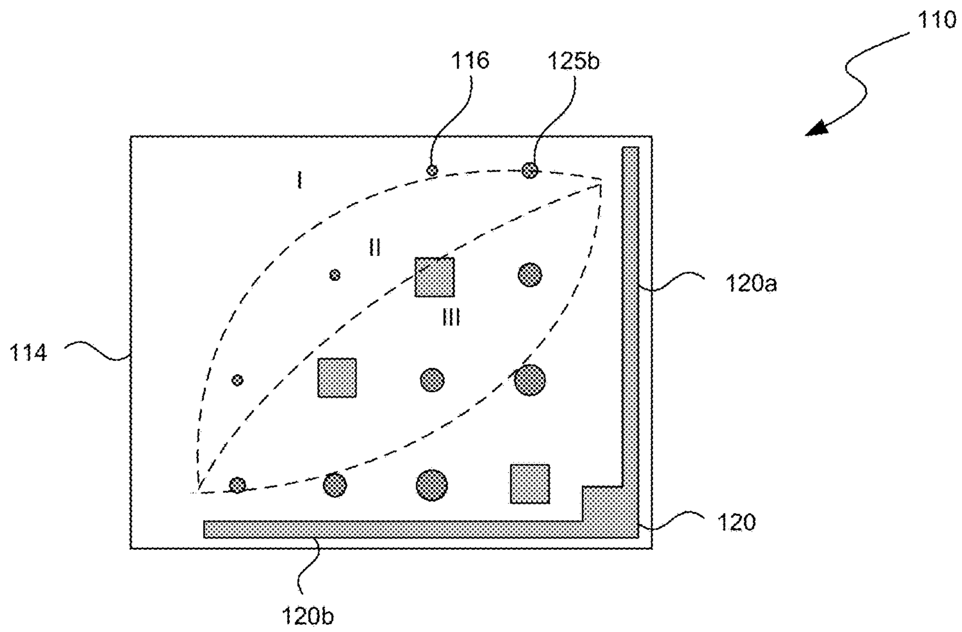

FIG. 3C

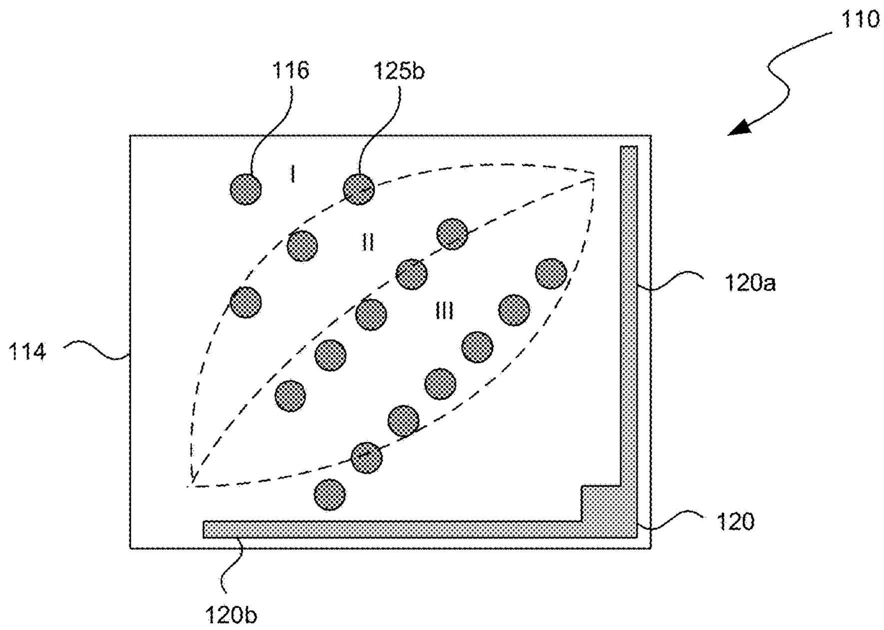

FIG. 3D

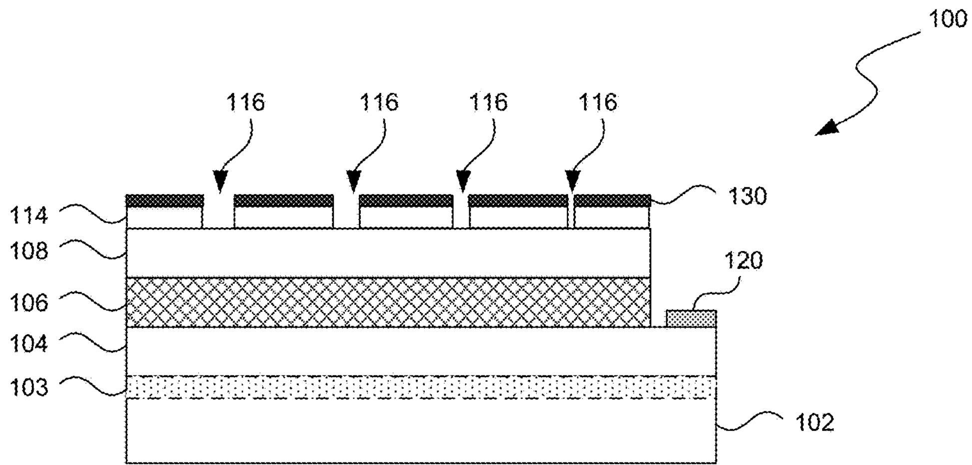

FIG. 4A

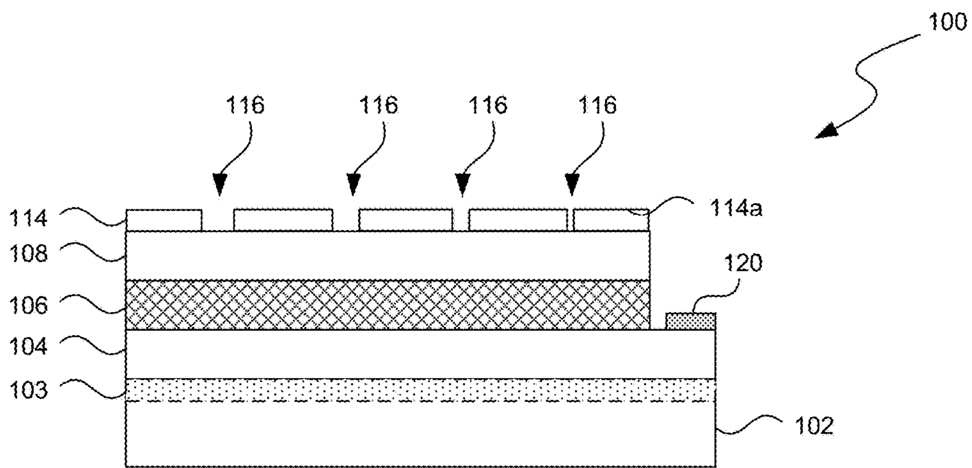

FIG. 4B

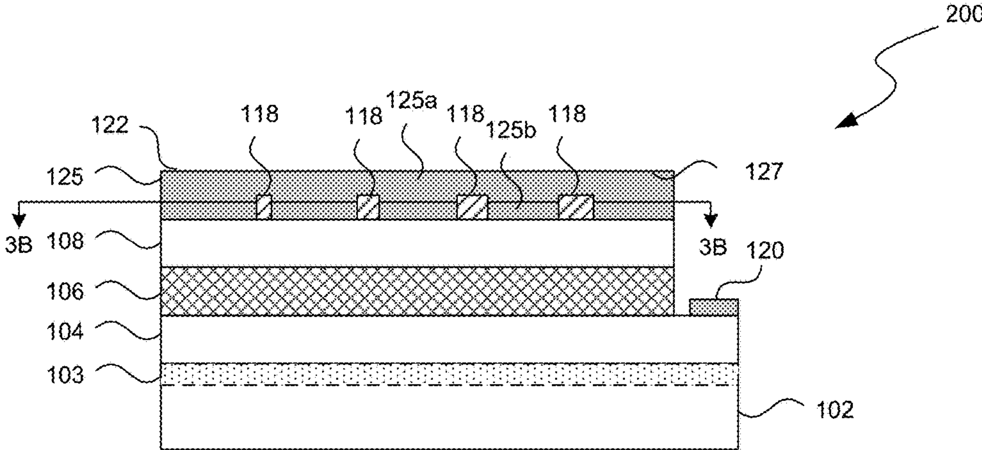

FIG. 5A

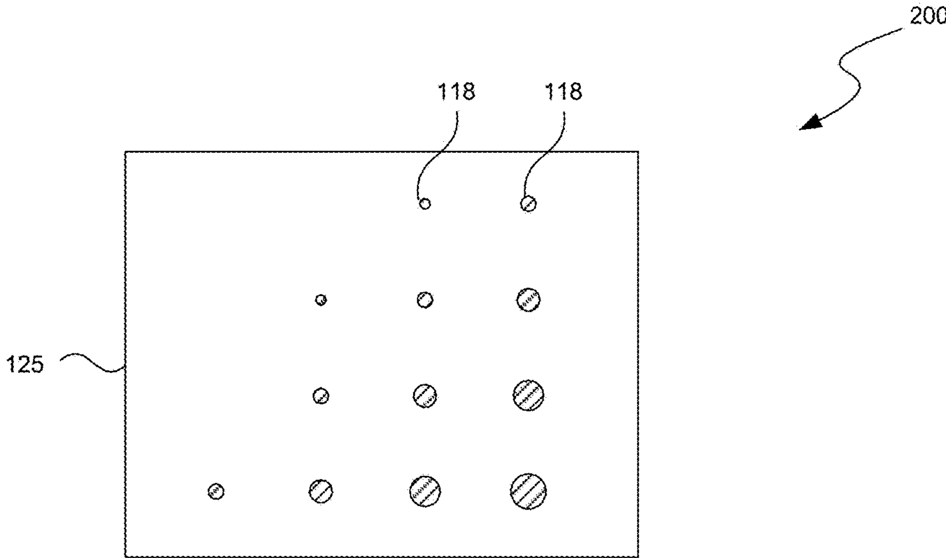

FIG. 5B

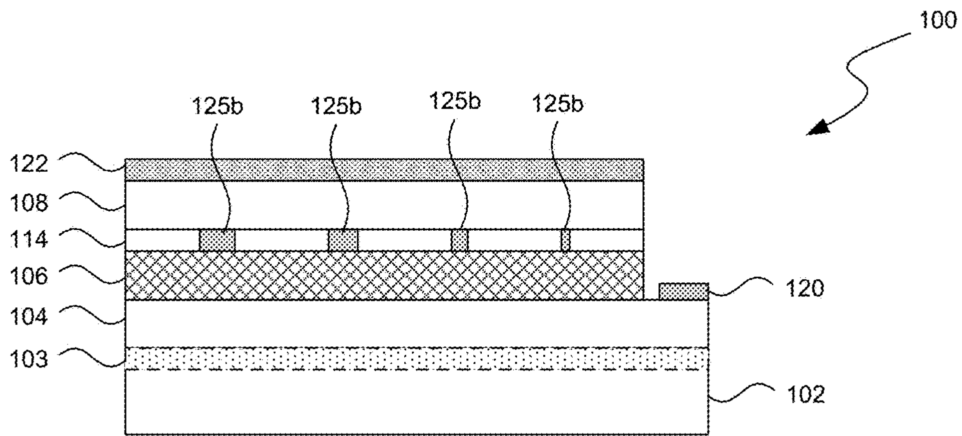

FIG. 6A

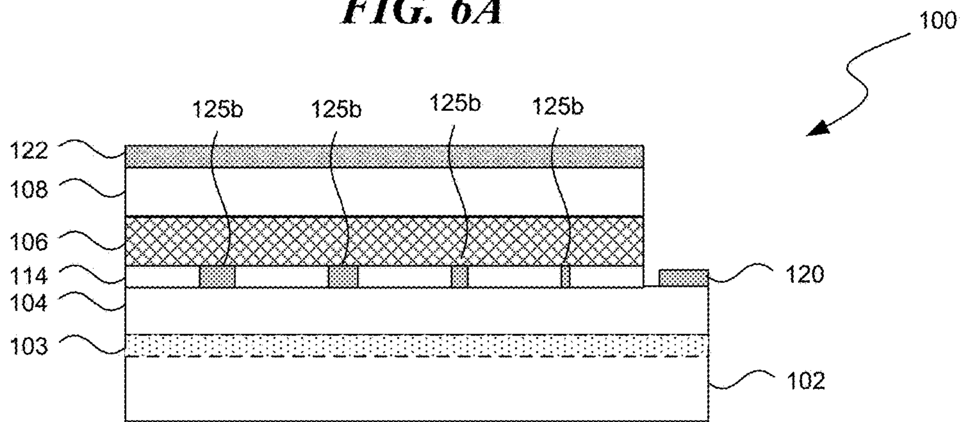

FIG. 6B

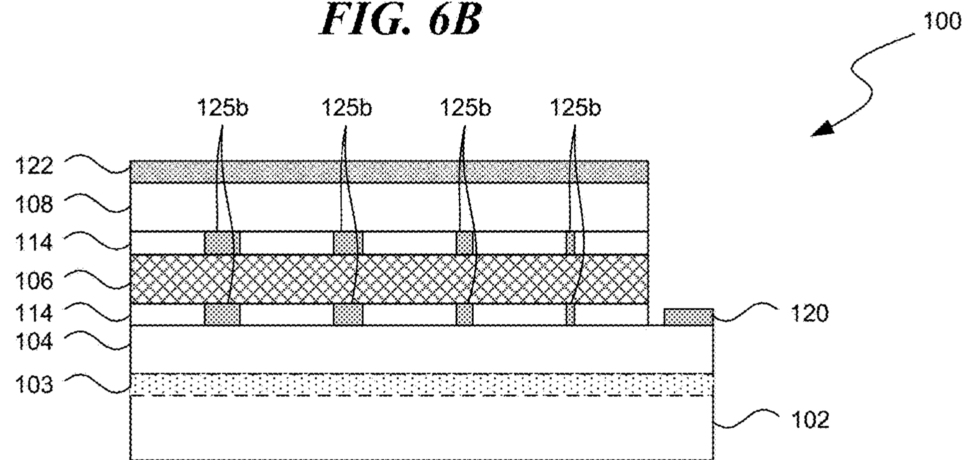

FIG. 6C

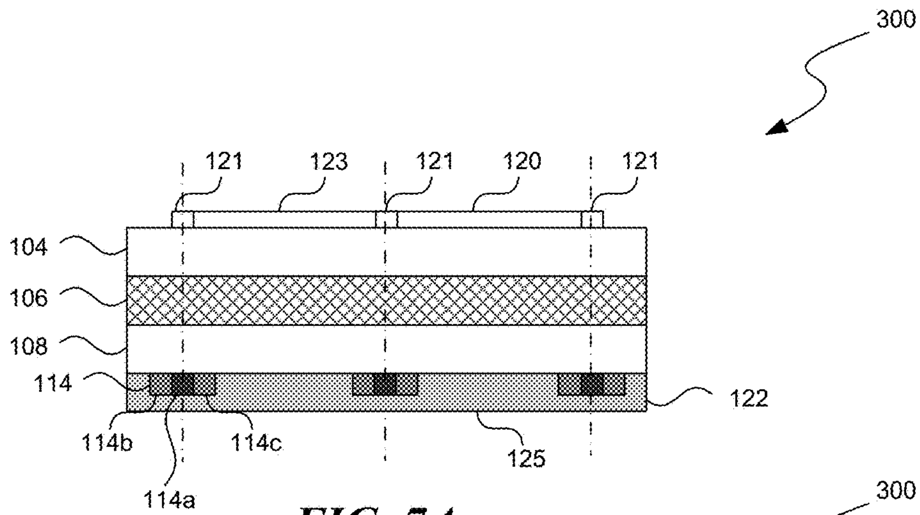

FIG. 7A

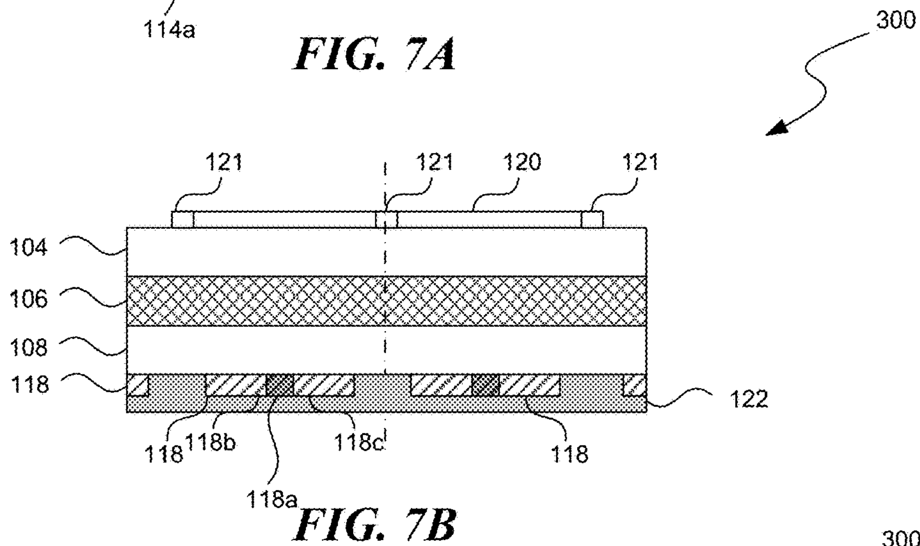

FIG. 7B

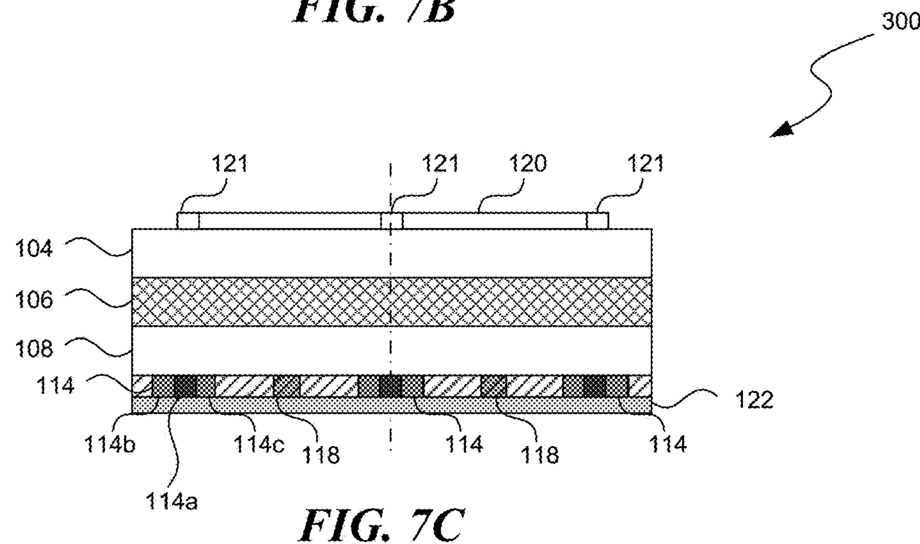

FIG. 7C

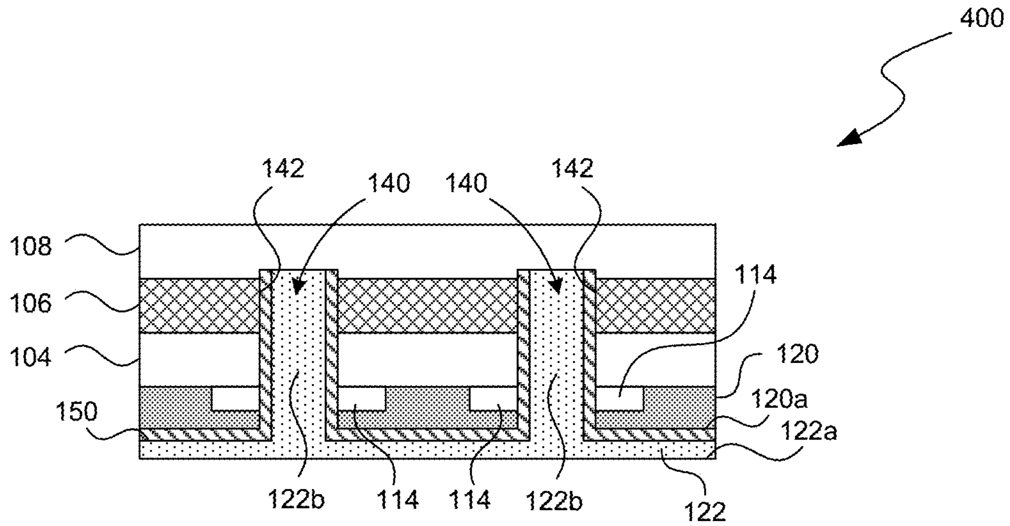

FIG. 8A

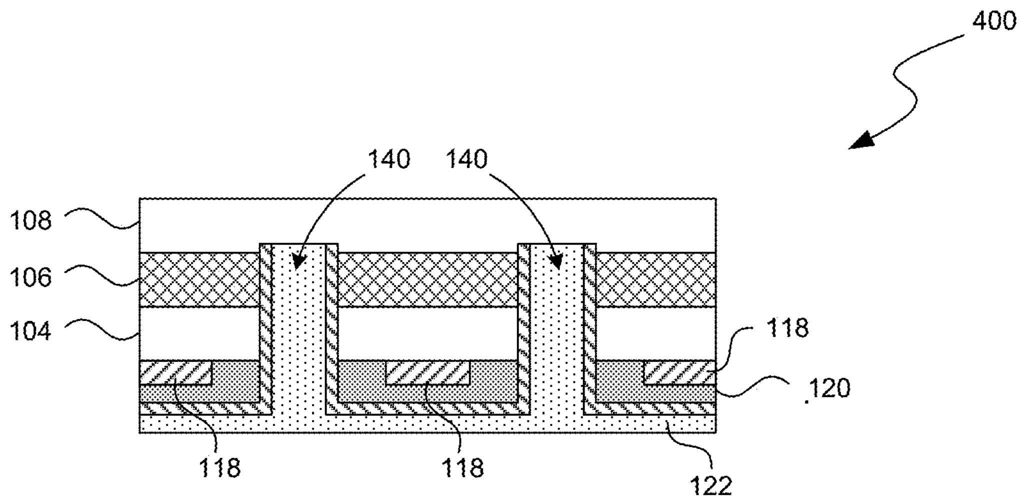

FIG. 8B

SOLID STATE LIGHTING DEVICES WITH IMPROVED CONTACTS AND ASSOCIATED METHODS OF MANUFACTURING

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a divisional of U.S. patent application Ser. No. 14/046,719 filed Oct. 4, 2013, which is a divisional of U.S. application Ser. No. 12/872,092 filed Aug. 31, 2010, each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure is related to solid state lighting ("SSL") devices with improved contacts and associated methods of manufacturing.

BACKGROUND

Mobile phones, personal digital assistants ("PDAs"), digital cameras, MP3 players, and other portable electronic devices utilize SSL devices (e.g., light emitting diodes (LEDs)) for background illumination. SSL devices are also used for signage, indoor lighting, outdoor lighting, and other types of general illumination. FIGS. **1**A and **1**B are cross-sectional and plan views of a conventional SSL device **10** with lateral contacts, respectively. As shown in FIG. **1**A, the SSL device **10** includes a substrate **12** carrying an LED structure **11** having N-type gallium nitride (GaN) **14**, GaN/indium gallium nitride (InGaN) multiple quantum wells ("MQWs") **16**, and P-type GaN **18**. Referring to FIGS. **1**A and **1**B, the SSL device **10** also includes a first contact **20** on the N-type GaN **14** and a second contact **22** (shown with a transparent current spreading material **29**) on the P-type GaN **18**. The first and second contacts **20** and **22** also include first and second contact fingers **20***a*, **20***b*, **22***a*, and **22***b* (FIG. **1**B), respectively. FIGS. **2**A and **2**B are cross-sectional and plan views of another conventional SSL device **10'** with vertical contacts, respectively. The first contact **20** includes a plurality of conductive fingers **21** (three are shown for illustration purposes) coupled to one another by a cross member **23**. The second contact **22** includes a reflective and conductive material (e.g., aluminum).

In operation, a continuous or pulsed electrical voltage is applied between the first and second contacts **20** and **22**. In response, an electrical current flows from the first contact **20**, through the P-type GaN **18**, the GaN/InGaN MQWs **16**, and the N-type GaN **14**, to the second contact **22**. The GaN/InGaN MQWs **16** then convert a portion of the electrical energy into light. The generated light is emitted from the SSL devices **10** and **10'** for illumination, signage, and/or other suitable purposes.

It is believed that SSL devices can operate at peak efficiencies when current densities are at or near a threshold level in the SSL devices. However, as discussed in more detail later, the current densities through different regions of the GaN/InGaN MQWs **16** in the SSL devices **10** and **10'** can be spatially non-uniform. For example, as shown in FIG. **1**B, certain regions (e.g., regions II and III) of the GaN/InGaN MQWs **16** of the SSL device **10** may operate at lower current densities than other regions (e.g., region I) of the GaN/InGaN MQWs **16**. In another example, the SSL device **10'** can have varying current densities based on the location of the conductive fingers **21**. Such spatially varying current densities can reduce the overall operating efficiency of the SSL devices **10** and **10'**. Accordingly, several improvements to balance regional current densities in SSL devices may be desirable.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a schematic cross-sectional diagram of an SSL device in accordance with the prior art.

FIG. **1**B is a schematic plan view of the SSL device in FIG. **1**A.

FIG. **2**A is a schematic cross-sectional diagram of another SSL device in accordance with the prior art.

FIG. **2**B is a schematic plan view of the SSL device in FIG. **2**A.

FIG. **3**A is a cross-sectional view of a SSL device in accordance with embodiments of the technology.

FIGS. **3**B-**3**D are plan views of a portion of the SSL device in FIG. **3**A in accordance with embodiments of the technology.

FIGS. **4**A-**4**B are cross-sectional views of a microelectronic substrate undergoing a process for forming the SSL device in FIG. **3**A.

FIG. **5**A is a cross-sectional view of another SSL device in accordance with embodiments of the technology.

FIG. **5**B is a plan view of a portion of the SSL device in FIG. **5**A.

FIGS. **6**A-**6**C are cross-sectional views of another SSL device in accordance with embodiments of the technology.

FIGS. **7**A-**7**C are cross-sectional views of yet another SSL device in accordance with embodiments of the technology.

FIGS. **8**A and **8**B are cross-sectional views of a further SSL device in accordance with embodiments of the technology.

DETAILED DESCRIPTION

Various embodiments of SSL devices with improved contacts and associated methods of manufacturing are described below. As used hereinafter, the term "SSL device" generally refers to devices with LEDs, organic light emitting diodes ("OLEDs"), laser diodes ("LDs"), polymer light emitting diodes ("PLEDs"), and/or other suitable radiation devices other than electrical filaments, a plasma, or a gas. A person skilled in the relevant art will also understand that the technology may have additional embodiments and may be practiced without several of the details of the embodiments described below with reference to FIGS. **3**A-**8**B.

FIG. **3**A is a schematic cross-sectional diagram of an SSL device **100** in accordance with embodiments of the technology. As shown in FIG. **3**A, the SSL device **100** can include a substrate material **102**, an optional buffer material **103**, a first semiconductor material **104**, an active region **106**, and a second semiconductor material **108**. The SSL device **100** also can also include a first contact **120** on the first semiconductor material **104** and a second contact **122** on the second semiconductor material **108**. In the illustrated embodiment, the first and second contacts **120** and **122** are arranged laterally relative to each other. In other embodiments, the first and second contacts **120** and **122** can also be arranged vertically relative to each other or in some other suitable contact configuration, as discussed in more detail below with reference to FIGS. **4**A-**7**B. In any of these embodiments, the SSL device may optionally include a reflective material (e.g., a silver film), a carrier material (e.g., a ceramic substrate), an optical component (e.g., a collimator), and/or other suitable components.

In certain embodiments, the substrate material **102** can include silicon (Si), at least a portion of which has the Si(1,1,1) crystal orientation. In other embodiments, the substrate material **102** can include silicon with other crystal orientations (e.g., Si(1,0,0)), AlGaN, GaN, silicon carbide (SiC), sapphire (Al_2O_3), zinc oxide (ZnO_2), a combination of the foregoing materials and/or other suitable substrate materials. In the illustrated embodiment, the substrate material **102** has a generally planar surface **111** proximate to the optional buffer material **103**. In other embodiments, the substrate material **102** may also include a non-planar surface (e.g., having openings, channels, and/or other surface features, not shown).

The optional buffer material **103** can facilitate the formation of the first and second semiconductor materials **104** and **108** and the active region **106** on the substrate material **102**. In certain embodiments, the optional buffer material **103** can include at least one of aluminum nitride (AlN), aluminum-gallium nitride (AlGaN), zinc nitride (ZnN), GaN, and/or other suitable materials. In other embodiments, the optional buffer material **103** may be omitted, and the first semiconductor material **104** may be formed directly on the substrate material **102**.

In certain embodiments, the first semiconductor material **104** can include N-type GaN (e.g., doped with silicon (Si)), and the second semiconductor material **108** can include P-type GaN (e.g., doped with magnesium (Mg)). In other embodiments, the first semiconductor material **104** can include P-type GaN, and the second semiconductor material **108** can include N-type GaN. In further embodiments, the first and second semiconductor materials **104** and **108** can individually include at least one of gallium arsenide (GaAs), aluminum gallium arsenide (AlGaAs), gallium arsenide phosphide (GaAsP), gallium(III) phosphide (GaP), zinc selenide (ZnSe), boron nitride (BN), AlGaN, and/or other suitable semiconductor materials.

The active region **106** can include a single quantum well ("SQW"), MQWs, and/or a bulk semiconductor material. As used hereinafter, a "bulk semiconductor material" generally refers to a single grain semiconductor material (e.g., InGaN) with a thickness greater than about 10 nanometers and up to about 500 nanometers. In certain embodiments, the active region **106** can include an InGaN SQW, GaN/InGaN MQWs, and/or an InGaN bulk material. In other embodiments, the active region **106** can include aluminum gallium indium phosphide (AlGaInP), aluminum gallium indium nitride (AlGaInN), and/or other suitable materials or configurations.

In certain embodiments, the first semiconductor material **104**, the active region **106**, the second semiconductor material **108**, and the optional buffer material **103** can be formed on the substrate material **102** via metal organic chemical vapor deposition ("MOCVD"), molecular beam epitaxy ("MBE"), liquid phase epitaxy ("LPE"), and/or hydride vapor phase epitaxy ("HVPE"). In other embodiments, at least one of the foregoing components may be formed via other suitable epitaxial growth techniques.

As shown in FIG. **3**B, the first contact **120** can include first lateral and first transverse contact fingers **120***a* and **120***b* extending along the X- and Y-axes, respectively. The first contact **120** can include copper (Cu), aluminum (Al), silver (Ag), gold (Au), platinum (Pt), and/or other suitable conductive materials. Techniques for forming the first contact **120** can include MOCVD, MBE, spray pyrolysis, pulsed laser deposition, sputtering, electroplating, and/or other suitable deposition techniques. In other embodiments, the first contact **120** can include other suitable configurations.

Referring back to FIG. **3**A, the second contact **122** can include an insulative material **114** and a conductive material **125** that is on and/or through at least a portion of the insulative material **114**. The insulative material **114** can include one or more openings **116** (e.g., vias) extending between the second semiconductor material **108** and a top surface **114***a* of the insulative material **114**. Four openings **116** are shown in FIG. **3**A for illustration purposes, though in other embodiments, the insulative material **114** can include one, two, three, five, or any other desired number of openings **116**. In certain embodiments, the insulative material **114** can include silicon dioxide (SiO2), silicon nitride (SiN), and/or other dielectric materials. In other embodiments, the insulative material **114** can include doped or un-doped silicon (Si), germanium (Ge), gallium arsenide (GaAs), and silicon carbide (SiC), and/or other suitable semiconductor materials. In further embodiments, the insulative material **114** can include a combination of the foregoing dielectric and semiconductor materials.

The conductive material **125** can include a first portion **125***a* on the top surface **114***a* of the insulative material **114** and a second portion **125***b* in the openings **116** of the insulative material **114**. The second portion **125***b* and the corresponding openings **116** are referred to herein after as "contact portions." In certain embodiments, the first and second portions **125***a* and **125***b* of the conductive material **125** can be the same material. For example, both the first and second portions **125***a* and **125***b* can include indium tin oxide ("ITO"). In other embodiments, the first and second portions **125***a* and **125***b* can include different transparent and conductive materials. For example, the first portion **125***a* can include ITO, and the second portion **125***b* can include aluminum zinc oxide ("AZO"), fluorine-doped tin oxide ("FTO"), and/or other suitable transparent and conductive oxide ("TCOs"). In further embodiments, the first portion **125***a* can include at least one of ITO, AZO, FTO, and/or other suitable TCOs, and the second portion **125***b* can include copper (Cu), aluminum (Al), silver (Ag), gold (Au), platinum (Pt), and/or other suitable conductive but non-transparent materials.

The contact portions can be configured to spatially control local current densities flowing through the regions of the SSL device **100**. Without being bound by theory, it is believed that the cross-sectional area and/or other characteristics of the individual contact portions may be proportional to or at least influence a contact resistance formed between the contact portions and the second semiconductor material **108**. As used herein, the term "contact resistance" generally refers to an electrical resistance as a result of two materials in direct contact with each other and forming an interface therebetween. As a result, in certain embodiments, at least one of a shape, size, geometric profile, configuration, and/or other characteristics of the individual contact portions can be adjusted to influence the contact resistance based on a target regional current density in the SSL device **100**. For example, as shown in FIG. **3**B, the individual contact portions can have different diameters in different regions of the SSL device **100**. As shown in FIG. **3**C, the individual contact portions can have different cross-sectional shapes in different regions of the SSL device **100**. In other embodiments, the contact portions may have generally similar or different sizes and/or shapes, and the number of contact portions in different regions of the SSL device **100** may be adjusted based on a target regional current density, as shown in FIG. **3**D. In further embodiments, the insulative material **114** may include a plurality of isolated "islands" (not shown) spaced apart by corresponding contact portions.

Several embodiments of the SSL device **100** can have more balanced current density profiles than conventional devices. For example, referring back to FIG. **1**B, it has been observed that regions I, II, and III of the conventional SSL device **10** can have different current densities during operation. In particular, it has been observed that, for example, region I tends to have higher current densities than region II, and region II has higher current densities than region III. Without being bound by theory, it is believed that such current density gradients are a result of varying electrical conductance (or resistance) along different current flow paths in the SSL device **10**. For example, locations in region I are closer to the first and second contact fingers **20***a* and **20***b* of the first contact **20** than those in regions II and III. As a result, region I has a higher electrical conductance (or lower resistance) than regions II and III, which tends to cause electrical currents to flow through region I more than through regions II and III. In other examples, depending on the conductivity of the first semiconductor material **104** and the current spreader layer **29**, the current density gradients discussed above may be reversed.

Referring back to FIGS. **3**A-**3**D, by modulating the contact resistance between the second contact **122** and the second semiconductor material **108**, an overall resistance of current flow paths in regions of the SSL device **100** can be manipulated. As a result, the SSL device **100** may have more balanced (e.g., uniform) current density profiles than those shown above in the Background section. For example, as shown in FIGS. **3**B-**3**D, the contact resistance of regions I and II of the SSL device **100** can be increased to be at least approximate or generally equal to that of region III by having smaller sized contact portions, a lower number of contact portions, and/or other suitable characteristics of the contact portions. As a result, during operation, more electrical current can be injected into Regions III such that the current flows generally evenly through regions I, II, and III to achieve a generally uniform current density profile in the SSL device **100**.

FIGS. **4**A and **4**B are cross-sectional views of a microelectronic substrate undergoing a process for forming the SSL device **100** in FIG. **3**A. As shown in FIG. **4**A, an initial stage of the process can include forming the first semiconductor material **104**, the active region **106**, and the second semiconductor material **108** on the substrate material **102** with the optional buffer material **103**. Another stage of the process can include depositing the insulative material **114** onto the second semiconductor material **108**. Techniques for depositing the insulative material **114** can include chemical vapor deposition ("CVD"), atomic layer deposition ("ALD"), spin coating, and/or other suitable deposition techniques. A masking material **130** (e.g., a photoresist) can then be formed on the top surface **114***a* of the insulative material **114** and patterned generally corresponding to the openings **116** (FIG. **3**A).

A portion of the insulative material **114** is then removed to form the openings **116**. Techniques for removing the insulative material **114** can include dry etching, wet etching, laser ablation, and/or other suitable material removal techniques. After forming the openings **116**, the masking material **130** can then be removed via wet etching and/or other suitable techniques, as shown in FIG. **4**B. The process can then include depositing the conductive material **125** in the openings **116** and on the top surface **114***a* of the insulative material **114** to yield the SSL device **100** as shown in FIG. **3**A. Techniques for depositing the conductive material **125** can include CVD, ALD, spin coating, and/or other suitable deposition techniques.

Even though the regional electrical resistance of the SSL device **100** is controlled or otherwise modulated by interposing a generally insulative material **114** between the conductive material **125** and the second semiconductor material **108** as shown in FIGS. **3**A-**3**D, in other embodiments, the regional electrical resistance can also be modulated by interposing a contact material between the conductive material **125** and the second semiconductor material **108**. FIGS. **5**A and **5**B are a cross-sectional view and a plan view of an SSL device **200** in accordance with additional embodiments of the technology. As shown in FIG. **5**A, the second contact **122** can include the conductive material **125** that encapsulates a plurality of pads of a contact material **118**. The conductive material **125** includes a generally continuous first portion **125***a* and a second portion **125***b* between adjacent pads of the contact material **118**. In the illustrated embodiment, the pads of the contact material **118** extend only partially from the second semiconductor material **108** into the conductive material **125**. In other embodiments, the pads of the contact material **118** may extend completely to a conductive surface **127** of the conductive material **125**.

The contact material **118** can form an interface with the second semiconductor material **108** with a lower contact resistance than can the conductive material **125**. For example, in one embodiment, the conductive material **125** includes at least one of ITO, AZO, FTO, and/or other suitable TCOs, and the contact material **118** can include copper (Cu), aluminum (Al), silver (Ag), gold (Au), platinum (Pt), and/or other suitable metals. Without being bound by theory, it is believed that TCOs tend to have higher contact resistance when formed on a semiconductor material than metals. In another embodiment, the conductive material **125** can include aluminum (Al), and the contact material **118** can include silver (Ag) or gold (Au), which are believed to have lower contact resistance when formed on a semiconductor material than aluminum. In further embodiments, the contact material **118** can form a generally Ohmic contact with the second semiconductor material **108** while the conductive material **125** forms a Schottky contact and/or other suitable types of at least partially resistive contact with the second semiconductor material **108**. In yet further embodiments, the conductive material **125** and the contact material **118** can include other suitable compositions and/or configurations.

Similar to the embodiments discussed above with reference to FIGS. **3**A-**3**D, the contact material **118** can be configured to spatially modulate current densities flowing through the specific regions of the SSL device **200**. For example, as shown in FIG. **5**B, the pads of the contact material **118** can individually have a size different than others in different regions of the SSL device **200**. It is believed that having larger pads of the contact material **118** can increase the current density through a particular region of the SSL device **200** over other regions because the contact material **118** has a lower contact resistance than the conductive material **125**. As a result, by adjusting at least one of a shape, size, geometric profile, configuration, and/or other characteristics of the individual pads of the contact material **118**, a generally uniform current density profile may be achieved in the SSL device **200**.

Even though the insulative material **114** and the contact material **118** are discussed above with reference to FIGS. **3**A-**3**D and **5**A as being on the second semiconductor material **108**, in other embodiments, the insulative material **114** and/or the contact material **118** can also have other structural arrangements. For example, as shown in FIG. **6**A,

the insulative material **114** and the corresponding second portion **125***b* of the conductive material **125** can be located between the active region **106** and the first semiconductor material **104**. In another example, as shown in FIG. **6**B, the insulative material **114** and the corresponding second portion **125***b* of the conductive material **125** can be located between the active region **106** and the first semiconductor material **104**. In a further example, as shown in FIG. **6**C, the SSL device **100** may have the insulative material **114** and the corresponding second portion **125***b* in more than one location. In any of these embodiments, the current density through the active region **106** is controlled by the pattern, size and/or shape of the conductive material **125** in the openings **116** of the insulative material **114** as described above with reference to FIGS. **3**A-**3**D.

FIGS. **7**A-**7**C are cross-sectional views of an SSL device **300** with vertical contacts in accordance with embodiments of the technology. As shown in FIG. **7**A, the SSL device **300** can include a first contact **120** spaced apart from a second contact **122**. The first contact **120** can include contact fingers **121** and a cross member **123** generally similar to the contact fingers **21** and cross member **23** discussed above with reference to FIG. **2**B.

The second contact **122** can include a conductive material **125** that at least partially encapsulates portions of an insulative material **114**; each portion of the insulative material **114** corresponds to one of the contact fingers **121**. The insulative portions can have different contact resistance for controlling and/or otherwise modulating a regional current density. For example, as shown in FIG. **7**A, the insulative material **114** can include a first insulative portion **114***a* generally aligned with the corresponding contact finger **121**. A second insulative portion **114***b* and a third insulative portion **114***c* straddle the first insulative portion **114***a*. In certain embodiments, the first insulative portion **114***a* can have a higher contact resistance than the second and third insulative portions **114***b* and **114***c*, which may have a higher contact resistance than the conductive material **125**.

Referring back to FIGS. **2**A and **2**B, without being bound by theory, it is believed that the areas underneath the contact fingers **21** and the cross member **23** in the SSL device **10'** tend to have the highest current densities because these areas provide the shortest paths for the electrical current to flow through. Other areas (e.g., those laterally spaced apart from the contact fingers **21**) tend to have lower current densities because these areas provide longer paths for the electrical current to flow through. As a result, by modulating the contact resistance in the areas immediately underneath the contact fingers **121** and the cross member **123**, current injection into the SSL device **300** may be manipulated such that the SSL device **300** may have a balanced (e.g., uniform) current density profile in a lateral direction in the SSL device **300**.

In certain embodiments, instead of increasing the contact resistance of areas underneath the contact fingers **121**, the contact resistance of other areas may be modulated by incorporating a contact material **118** having portions with different contact resistance. For example, as shown in FIG. **7**B, the contact material **118** may be placed in areas laterally spaced apart from the contact fingers **121**. The contact materials **118** can have a lower contact resistance than the conductive material **125**. As a result, the areas corresponding to the contact material **118** can have a lower electrical resistance than areas underneath the contact fingers **121**. In the illustrated embodiment, the contact material **118** has first, second, and third portions **118***a*, **118***b*, and **118***c*. The first portion **118***a* has an contact resistance lower than the second and third portions **118***b*. In other embodiments, the contact material **118** can include other suitable number of portions. In further embodiments, the SSL device **300** may include both the contact material **118** and the insulative material **114**, as shown in FIG. **7**C.

FIGS. **8**A and **8**B are cross-sectional views of an SSL device **400** in accordance with further embodiments of the technology. As shown in FIG. **8**A, the SSL device **400** can include a plurality of openings **140** extending from a surface **120***a* of the first contact **120** toward the second semiconductor material **108**. The SSL device **400** also includes an isolation material **150** on the surface **120***a* of the first contact **120** and the side walls **142** of the openings **140**. The second contact **122** includes a first portion **122***a* on the isolation material **150** and second portions **122***b* in the openings **140**.

As shown in FIG. **8**A, the SSL device **400** can further include a plurality of pads of insulative material **114** generally straddling the individual openings **140**. The pads of insulative material **114** can help to locally modulate the current density as described above with reference to FIGS. **3**A-**3**D. Even though only one insulative portion is shown for each of the pads of insulative material **114**, in certain embodiments the pads of insulative material **114** can individually include a plurality of insulative portions as described above with reference to FIG. **7**A. FIG. **8**B shows another embodiment of the SSL device **400** in which a plurality of pads of contact material **118** are placed in areas spaced apart from the openings **140**. The pads of contact material **118** can also help to provide a generally uniform current density profile in the SSL device **400** as discussed above with reference to FIG. **7**B.

From the foregoing, it will be appreciated that specific embodiments of the technology have been described herein for purposes of illustration, but that various modifications may be made without deviating from the disclosure. In addition, many of the elements of one embodiment may be combined with other embodiments in addition to or in lieu of the elements of the other embodiments. As such, many of the foregoing embodiments have contacts with first and second materials that have different electrical conductivities. The contacts are configured to form preferential current paths or defined current flow paths through the first and second semiconductor materials to at least mitigate non-uniformities in current densities across an SSL. Accordingly, the disclosure is not limited except as by the appended claims.

I claim:

1. A solid state lighting ("SSL") device, comprising:

an SSL structure having a first semiconductor material, a second semiconductor material spaced apart from the first semiconductor material, and an active region between the first and second semiconductor materials;

a first contact on the first semiconductor material;

a second contact on the second semiconductor material, the first and second contacts define a current flow path through the SSL structure;

an insulative material between the first semiconductor material and the active region or between the active region and the second semiconductor material;

the insulative material having a plurality of openings, at least one of the plurality of openings having a different shape or size from the other openings; and

a conductive material in the plurality of openings; and

wherein the first or the second contact is configured to provide defined current flow paths through the first and

second semiconductor materials that provide a current density profile in the SSL structure based on a target current density profile.

2. The SSL device of claim **1** wherein:

the first semiconductor material includes a P-type gallium nitride ("GaN") material;

the second semiconductor material includes an N-type GaN material;

the active region includes at least one of a bulk indium gallium nitride ("InGaN") material, an InGaN single quantum well ("SQW"), and GaN/InGaN multiple quantum wells ("MQWs"); and

the conductive material includes at least one of aluminum zinc oxide and fluorine-doped tin oxide.

3. The SSL device of claim **1** wherein:

the second contact is opposite the first contact; and

the first contact includes a conductive material on the first semiconductor material.

4. The SSL device of claim **1** wherein:

the second contact is opposite the first contact.

5. The SSL device of claim **1** wherein:

the second contact is opposite the first contact;

the contact material includes silver (Ag); and

the conductive material includes aluminum (Al).

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